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Performance Analysis and Application Evaluation of Highway Anchors

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ABSTRACT: In order to reduce large-scale excavation and to improve the stability of highway slope for the purpose of providing safe construction and smooth operation, ground anchors are commonly used in Taiwan. With the serving time increasing, the performance of ground anchors needs to be investigated for handling the first-hand information of the slope protection facilities. This is the reason to organize and assemble a database for ground anchor system. This study of anchor system collects the information of slope inspections, maintenance and operation of conservation, and anchor testing data. All the valuable anchor information, including head appearance, head component, endoscopic visual inspection, and lift-off test, are documented into the anchor database. Finally, a statistical research is conducted and the outcome is discussed in order to achieve the goal of sustainable highway.

KEYWORDS: Anchor, Corrosion, Prestress, Lift-off test.

1 INTRODUCTION

Slopes, hills, and terrain are accounted for more than 70% of the total area of Taiwan. As the population continues growing in recent years, accompanying with economic development and transport industries, highway construction along hillside gradually began to grow. In response to the changing of the geological environment in hilly areas along with rapid climate change, construction of highways extensively use the technique of ground anchors to fulfill engineering jobs for slope stability in recent years.

However, there is deterioration phenomenon of the anchors in recent times along with several cases of major disasters in Taiwan. Moreover, with the time increasing in conjunction with strong typhoons and earthquakes attack, the service functions of highway anchors are demanded for performance analysis and application evaluation. Due to the lack of comparative reference to follow, stability analysis of the relevant mechanisms of slope damage cannot be conducted precisely with consideration of anchor system performance. Therefore, it is desirable to generate the database system for the anchor information on the highway slope.

2 GROUND ANCHOR DATA FORMAT DESCRIPTION

To fulfill the conservation and management of the national highways, the transportation bureau of Public Works is set into three Agents, namely the Northern Agent, the Central Agent, and the Southern Agent. Under the three Agents, there are a number of Sections which are subdivided from the Agents in order to perform maintenance and management of slope stability of Public Works, respectively.

In this study, the initial system for the field test data of the ground anchors is followed with the form for the ground anchors on the demonstration slope. This form is used for the slope executing the demonstration of the effectiveness of conservation and management outcomes and adopted as the following system data design from the initial field of architecture. Since then, in order to integrate the rest of the performance test data from the contractors of Public Works Section, by means of adding and modifying data fields, the system can now include comprehensive information on all fields for the anchor test report of the Public Works Section.

In order to facilitate an effective investigation for all the information fields, in addition to listing the four test items, basic information and anchor design information are added in the data system. Therefore, the system can be roughly divided into six parts, namely Basic information, Anchor design data,

Anchor head appearance, Anchor head assembly view, Endoscopic view, and Lift-off test result.

Basic information fields contain 940 slopes with mileage, 139 anchor slopes, public works section, anchor panel type, serial number, completion dates, test dates, and test company; Anchor design data fields contain spacing, angle, total length, free section, grout segment, and design tensile force; Anchor head appearance fields contain hammer striking, protection appearance, compression plates appearance, compression plates engaging condition, water leaking situation, integrated assessment, and in-situ photo filename; Anchor head component fields contain pressurized plates size, pressurized plate angle, anchor head size, type of steel tendon, tendon remaining length, length of the free section without grout, corrosion situation, water leaking situation, and in-situ photo filename; Endoscopic view fields contain free section grout condition, strand spreading, grout/reverse pipe, internal humidity or ground water, corrosion condition, in-situ photo filename, and video name; Lift-off test result fields contain design tensile force, the maximum test load, the residual load, steel tendon rupture, pull-off section, test subsequent processing, classification, and in-situ photo filename.

In summary, National Highway Bureau manages 940 slopes, where 139 utilize anchors to stable themselves, Specific speaking, the Northern Agency has 90, the Central Agency has 20, and the Southern Agency has 29. The Northern Agency has five Sections with anchor slopes: Neihu, Chungli, Mucha, Kansai, and Toucheng. The Central Agency has three Sections with anchor slopes: Miaoli, Tachia, and Nantou. The Southern Agency has two Sections with anchor slopes: Baihe and Pingtung.

3 STATISTICAL ANALYSIS OF ANCHOR DATA

This study is able to look up the current situation of all anchors along the highways. The inspection data we used are come from the 139 anchor slopes with reference to the appropriate reports to develop testing operations with anchor evaluation points and principles. In order to find the service situation of all anchors along highway, the Highway Bureau make the rule for anchors were detected into four categories: (1) Anchor head appearance, (2) Anchor head component, (3) Endoscopic View, and (4) Lift-off test result. Each of the 4 categories are functional classification and then graded into five levels assessment XABCD. Engineers of Public Works Section can thus tell the overall anchor performance through the number of ratings obtained from functional status of each anchor (Table 1). Besides, in order to understand the exact number of engineering inspection and grading and assessment, all anchors of the four

above-mentioned detection results are statistical analysis and a comparison strip diagram for the Public Works Section are illustrated in Figure 1.

Table 1. Ground anchor test graded and quantitative assessment.

Anchor Head Appearance	Number	Percentage
D(normal)	13522	67.84 %
C(acceptable)	3534	17.73 %
B(not good)	2740	13.75 %
A(extremely poor)	72	0.36 %
X(Loss of function)	64	0.32 %
Total	19932	100.00 %

Anchor Head Component	Number	Percentage
D(normal)	3786	28.07 %
C(acceptable)	6506	48.24 %
B(not good)	1733	12.85 %
A(extremely poor)	1243	9.22 %
X(Loss of function)	220	1.63 %
Total	13488	100.00 %

Endoscopic View	Number	Percentage
D(normal)	2650	20.47 %
C(acceptable)	4719	36.45 %
B(not good)	3184	24.60 %
A(extremely poor)	2198	16.98 %
X(Loss of function)	194	1.50 %
Total	12945	100.00 %

Lift-off Test Result	Number	Percentage
D(normal)	559	42.25 %
C(acceptable)	327	24.72 %
B(not good)	161	12.17 %
A(extremely poor)	146	11.04 %
X(Loss of function)	130	9.83 %
Total	1323	100.00 %

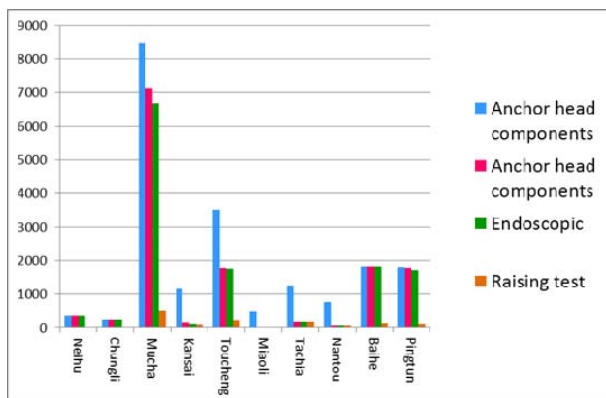


Figure 1. Ground anchor number for each section.

4 ANCHOR HEAD APPEARANCE

Through the appearance of the anchor head protection view, we can easily learn about the failure or corrosion due to slope sliding or groundwater level changes. According to the suspected condition of damage or corrosion, its results can provide the information for further inspection of anchor head component, endoscopic view and lift-off test. Exterior view of anchor head protection include: separation anchor head protector block, the appearance of block size, and the pressure panel (or lattice beams) between anchor head flipped or even if there is the phenomenon of falling, whether near the anchor head with efflorescence or groundwater leaking and so on.

Exterior view of anchor head, if the review showed no abnormal or normal water quality is rated as D grade (normal); if the review found that the surrounding environment is not conducive to long-term anchor functions (such as water seepage, efflorescence, or the appearance of a slight anchorage breakage) or moderately corrosive water quality, the rated C grade (acceptable); if the review found that ground anchor function may be compromised (such as the separation of less than 2 mm) or water quality as a significant corrosion is ranked B (not good); if the review found that ground anchor function is severely impaired (such as the separation is greater than 2 mm) or water quality as a strong corrosion is rated A-level (extremely poor); if found anchor head flip or fall, then named X loss of function level (Table 2).

Table 2. Classification of anchor head appearance.






Classification	Definition	Photo
X-level (X loss of function level)	Anchor head flip or fall.	
A-level (extremely poor)	1. Ground anchor function is severely impaired (such as the separation is greater than 2 mm). 2. A strong corrosion.	
B-level (not good)	1. Ground anchor function may be compromised (such as the separation of less than 2 mm). 2. Water quality as a significant corrosion	
C-level (acceptable)	1. The surrounding environment is not conducive to long-term anchor functions (such as water seepage, efflorescence, or the appearance of a slight anchorage breakage). 2. water quality as a significant corrosion.	
D-level (normal)	1. no abnormal. 2. normal water quality.	

5 ANCHOR HEAD COMPONENT

In order to observe the status of the anchor head component, after a visual inspection of appearance of the anchor, concrete block of the significant abnormal anchor are selected to be drilled for viewing anchor head component rust situation.

Anchor head component, if the review showed no corrosion or no water seepage, then named D grade (normal); if the review results have slight corrosion or water seepage, or anchor heads have corrosion phenomenon, rust shallow depth, unable to measure or less than 0.1 mm were then awarded C grade (acceptable); if the review found that severe corrosion or water seepage anchor head, or the anchor head has a deep rust, tendons or local anchor head surface rust visible debris and cracks, but the distribution of the surface area less than 50 percent who are rated as class B (not good); review found that the anchor head has a deep rust, tendons or anchor head surface rust debris and cracks visible local distribution surface area greater than 50%, tendons cross section has been deformation due to corrosion and who then rated A (extremely poor); if the review found that components have been off (such as clip off, shrink or rupture within tendons, etc.), loss of function as the X-class (Table 3).

Table 3. Classification of anchor head components.

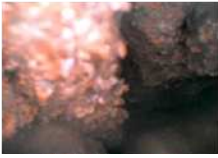




Classification	Definition	Photo
X-level (X loss of function level)	Components have been off (such as clip off, shrink or rupture within tendons, etc.), loss of function.	
A-level (extremely poor)	The anchor head has a deep rust, tendons or anchor head surface rust debris and cracks visible local distribution surface area greater than 50%, tendons cross section has been deformation due to corrosion.	
B-level (not good)	That severe corrosion or water seepage anchor head, or the anchor head has a deep rust, tendons or local anchor head surface rust visible debris and cracks, but the distribution of the surface area less than 50 percent.	
C-level (acceptable)	The review results have slight corrosion or water seepage, or anchor heads have corrosion phenomenon, rust shallow depth, unable to measure or less than 0.1 mm.	
D-level (normal)	No corrosion or no water seepage.	

6 ENDOSCOPIC VIEW

Endoscopy can be used to view the status anchor rusting steel tendons back of the head. In general, viewing depth is just about 1m due to the tendons close to each other and rotation arrangement. Endoscopic view, view the results if it is not

abnormal or corroded area of not reached 10%, the rated D grade (normal); if the review results tendons brown, but the surface is smooth or corroded area between 10 to 50% who then rated C grade (acceptable); if the review found that tendons Cheng dark brown, slightly rough surface, no coral or tubercles or corroded area between 50 to 90% who are named B level (poor); if review found that tendons dark brown, the surface has coral-like or tubercles or corroded area of more than 90%, rated A (extremely poor); if the review found that steel strand tendon rupture or spread and comprehensive corrosion, and loss of function of the rated X (Table 4).

Table 4. Classification of endoscopic view.

Classification	Definition	Photo
X-level (X loss of function level)	That steel strand tendon rupture or spread and comprehensive corrosion.	
A-level (extremely poor)	That tendons dark brown, the surface has coral-like or tubercles or corroded area of more than 90%.	
B-level (not good)	That tendons Cheng dark brown, slightly rough surface, no coral or tubercles or corroded area between 50 to 90%.	
C-level (acceptable)	The review results tendons brown, but the surface is smooth or corroded area between 10 to 50%.	
D-level (normal)	It is not abnormal or corroded area of not reached 10%	

7 LIFT-OFF TEST RESULT

Residual load view, if the residual load between the design load of from 0.8 to 1.2 (0.8 Tw <Tr <1.2 Tw), as the D-level (normal); if the residual load between the design load of from 0.5 to 0.8 (0.5 Tw <Tr <0.8 Tw), is rated C grade (acceptable); if the residual load design load ranging from 0.2 to 0.5 (0.2 Tw <Tr <0.5 Tw), then rated B (poor); if residual load greater than 1.2 or less than 0.2 design load design load (Tr > 1.2 Tw or Tr < 0.2 Tw), then rated A (extremely poor); if during the test strand break or pull off the Ground anchor, the commentary loss of function of X.

8 SUMMARY

8.1 Anchor head appearance inspection outcomes

The comprehensive assessment of the anchor head appearance is described as follow. Total Integration anchor head appearance is 19932, which has 13522 to anchor function was rated D grade (normal), accounting for 67.84%; 3534 has been named ground anchor function C grade (acceptable),

accounting overall 17.73%; 2740 has ground anchor the function is rated B (poor), accounting for 13.75%; there are 72 ground anchor function was rated A-level (extremely poor), accounting for only 0.36% overall; there are 64 ground anchor function was rated X-rated functional loss, accounting for only 0.32% overall, the final results will be merged into a pie chart showing the proportion anchor test items graded case (Fig. 2).

8.2 Anchor head components inspection outcomes

The comprehensive assessment of the anchor head appearance is described as follow. Total Integration anchor head appearance is 19932, which has 13522 to anchor function was rated D grade (normal), accounting for 67.84%; 3534 has been named ground anchor function C grade (acceptable), accounting overall 17.73%; 2740 has ground anchor the function is rated B (poor), accounting for 13.75%; there are 72 ground anchor function was rated A-level (extremely poor), accounting for only 0.36% overall; there are 64 ground anchor function was rated X-rated functional loss, accounting for only 0.32% overall, the final results will be merged into a pie chart showing the proportion anchor test items graded case (Fig. 2).

8.3 Endoscopic view outcomes

The integrated assessment of the anchor endoscopic inner view is illustrated as follow. Integration through the endoscope to view a total 12945, of which 2650 were rated ground anchor function D grade (normal), accounting for 20.47%; 4719 has been named ground anchor function C grade (acceptable), Its share in total 36.45%; the 3184 ground anchor function is rated B (poor), accounting for 24.60%; 2198 has ground anchor the function is rated A-level (extremely poor), accounting for 16.98%; last there are 194 ground anchor function was rated X-rated functional loss, accounting for only 1.50% overall, the final will be merged into a pie chart showing the proportion anchor test items graded case (Fig. 4)

8.4 Lift-off test results outcomes explained

The integrated assessment of is described as follow. Integration lift-off test through a total of 1,323, of which 559 were rated ground anchor function D grade (normal), accounting for 42.25%; there are 327 ground anchor function was rated C grade (acceptable), accounting overall 24.72%; there are 161 ground anchor function is rated B (poor), accounting for 12.17%; 146 ground anchor have been rated A-level functions (extremely poor), accounting for 11.04%; finally there are 130 ground anchor function was rated X-rated functional loss, accounting for 9.83%, and finally merged into a pie chart showing the proportion of circumstances ground anchor grading of test items (Fig. 5).

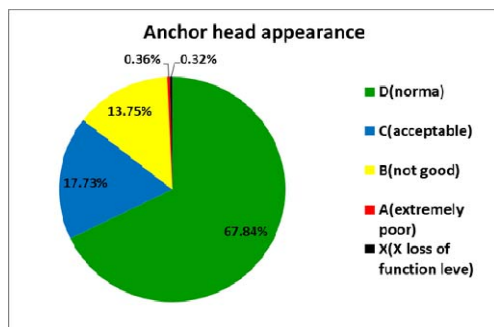


Figure 2. Anchor head appearance.

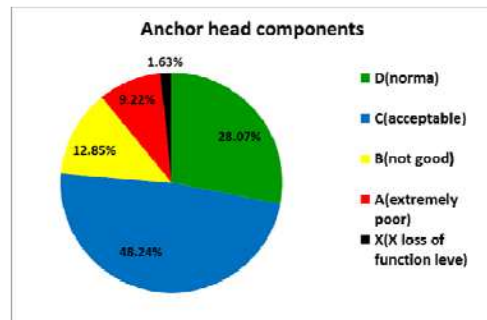


Figure 3. Anchor head components.

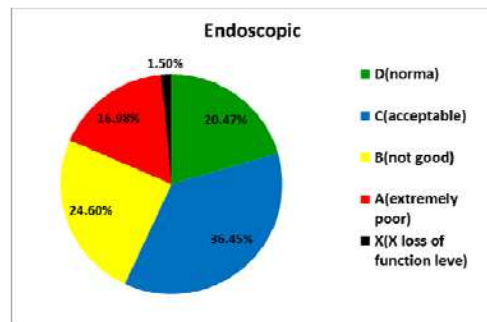


Figure 4. Endoscopic view.

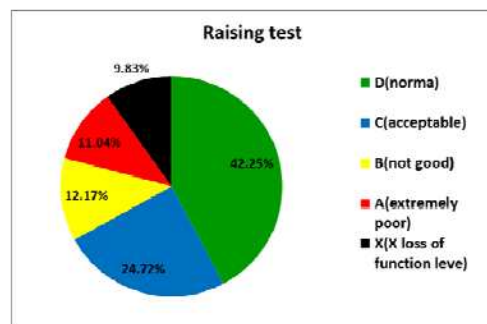


Figure 5. Lift-off test results.

9 CONCLUSIONS

It is found that ground anchor head appearance condition of D grade (normal) is 68% of the total counts Ground anchor; the anchor head component status is D grade (normal), only the total ground anchor the number of 28%, while the situation for the class C (acceptable), the total number is 48 percent anchor; ground anchor endoscopic view belong to D grade (normal), only the total counts of ground anchor 20%, while the situation for the class C (acceptable) is 36% of the total counts of ground anchor; ground anchor lift-off test condition is D grade (normal) is 42% of the total counts of ground anchor, and availability grade C (acceptable) is 25% of the total ground anchor counts. In summary, it can be found that about 70% of the anchor head appearance, anchor head components, endoscopic view, and the lift-off test status are in the right place to good range, and the most important anchor residual load for the overall presentation perform as well.

10 REFERENCES

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